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Energy Storage

Leading Ontario to a Emission-free Electricity System

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Contents

Introduction

What do Ontarians expect from and hope to achieve with their energy infrastructure? Public opinion[1] and policy decisions[2] are leading the Province to reduce investment in technologies and fuel sources that contribute to local, regional and global environmental degradation.[3] Simultaneously, investment in green energy has increased with the aim of building an electrical grid that is environmentally and socially sustainable[4] while providing an economic, efficient, and resilient electricity system.[5] A significant factor limiting deployment of renewable energy systems in Ontario is variability of generation[6] and lack of dispatchability.[7] Ideal application of energy storage can provide the capability to lead Ontario to an emissions-free energy future based on renewable resources.

Purpose of Research

The purpose of this research is to understand the role that energy storage plays in the current energy supply mix of Ontario and its potential to expand the role of renewable energy (RE) and reduce carbon emissions from electrical generation.

To achieve this goal it was necessary to first understand what is meant by the term energy storage, review the benefits that storage technologies can provide to electricity systems with and

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[1] Murray Elston, Floyd Laughren, and David McFadden. *Renewing Ontario's Electricity Distribution Sector: Putting the Consumer First*. Ontario Distribution Sector Review Panel. (2012): 21.

[2] Ontario. Green Energy Act, 2009, SO 2009, c 12, Sch A.

[3] Winfield, Mark S.. *Blue-Green Province: The Environment and the Political Economy of Ontario.* Vancouver, BC: UBC Press (2012): 137.

[4] Ontario. Ministry of Energy. *Achieving Balance - Ontario's Long Term Energy Plan*. Toronto, Ontario: Queen's Printer for Ontario. (2013): 30.

[5] Ibid., 2.

[6] Rick McKitrick and Kenneth P. Green. *Environmental and Economic Consequences of Ontario's Green Energy Act.* Toronto: Fraser Institute. (2013): 23.

[7] Lynda O'Malley, Jesika Briones, Dan Goldberger. *Storage Working Group Briefing Paper*. Toronto: Ontario Sustainable Energy Association. (2010): 6.

without relation to renewable energy. Second, it was necessary to understand how electricity systems are organized and regulated and why this impacts development of energy storage. Third, it was necessary to understand the case of Ontario; the regulatory environment, existing energy storage facilities, and influence of renewable energy.

Organization

This paper is divided into three sections; Technology Overview, Renewable Energy Penetration, and Policy Review. Technology Overview discusses specific techniques for storing energy and practicability in Ontario. Renewable Energy Penetration focuses on energy storage as enabling technology for increasing the share of RE in Ontario's electricity supply mix. Policy Review provides an analysis of current energy policy and planning in Ontario as it relates to Energy Storage Systems (ESS) and renewable energy systems (RES).

Methodology

The research for this paper was conducted through literature review and policy analysis.

Literature Review

To understand and convey the viability of the various energy storage technologies available, this paper reviews academic literature on techniques, operational characteristics, technical requirements, benefits and limitations and cost.

To understand the role that energy storage can play in increasing penetration of renewable energy this paper reviews common issues associated with intermittent resources and variable generation and literature on the alignment of energy storage capabilities.

To understand the impact that electricity system regulations have on the deployment of energy storage this paper reviews literature on common historic regulatory frameworks, market organization in unbundled markets, barriers and limitations presented by these policies and policy alternatives explored in other jurisdictions.

Policy Analysis

The policy research includes analysis of Ontario's Long Term Energy Plan (LTEP) and related policies as well as government publications on the electricity market supply mix with a focus on energy storage. There are a variety of policy documents regarding the creation of a green energy marketplace and thus ample literature through which to determine the Government's expectations for future penetration of RE and ESS including the LTEP.

Secondary research was conducted to understand these policies in the context of other territories and jurisdictions, the barriers and solutions presented elsewhere, and critiques of policies supporting renewable energy.

Summary: Technology Overview

This section provides a brief overview of grid-scale Energy Storage System (ESS) technology; characteristics and applications, which are presently operational in Ontario, and which are commercially available but as yet not widely deployed.

ESS technology includes a wide variety of systems; Pumped Hydroelectric Storage (PHS), battery systems, Compressed Air Energy Storage (CAES), flywheels, thermoelectric storage, hydrogen storage, and distributed storage such as electric vehicles. These varied systems are more or less practical in different settings based on local geography, economics, regulatory framework and other factors.

Ontario, because of its geography, is an optimal location for pumped hydroelectric and CAES though other technologies may also be practical.[8] Pumped hydroelectric is presently used within Ontario's electrical grid to utilize excess energy produced by nuclear facilities during times of low demand and to complement hydroelectric production such as the Sir Adam Beck Pump Generating Station at Niagara Falls.[9] Other technologies have been procured recently in Ontario such as flywheels, thermoelectric, and batteries.[10] [11]

Commercial viability is dependent upon regulatory environment, electricity pricing, demand, and technology cost variability.[12] Established technologies face fewer barriers to deployment while newer technologies are still being proving through demonstration projects.

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[8] Fabio Genoese and Massimo Genoese. 2014. "Assessing the Value of Storage in a Future Energy System with a High Share of Renewable Electricity Generation." *Energy Systems* 5 (1): 37.

[9] O'Malley et al., 9.

[10] IESO. *RFP for Energy Storage Services Backgrounder*. Toronto: Independent Electricity System Operator. (2014): 2.

[11] IESO. "Energy Storage." *Independent Electricity System Operator.* Accessed 23 February 2015.

[12] Michael Carbajales-Dale; Charles J. Barnhart, and Sally M. Benson. "Can we Afford Storage? A Dynamic Net Energy Analysis of Renewable Electricity Generation Supported by Energy Storage." *Energy & Environmental Science* 7 (5) (2014): 1539.

Summary: Renewable Energy Penetration

The penetration of renewable energy within the electricity market is limited by the level to which variable generation can be dispatched to meet demand.[13] Intermittent resources such as wind and solar generate electricity only when the resources are productive which may not coincide with consumer demand. Energy storage can be used to capture electricity when intermittent resources are available and dispatch it to the grid at times of high demand.[14] Additionally, increased shares of intermittent resources may result in increased need for grid regulation services which can be provided by ESS.[15]

There are several ways that ESS can enable RE penetration including combined RES/ESS plants, independent generation-side ESS which purchases and sells energy within the grid, and demand-side storage such as building-integrated ESS. The commercial viability of combined RES/ESS projects is of interest because operators of renewable generators can develop on-site storage facilities to increase the overall effectiveness and profitability of the plant.[16] Ontario has specifically stated that this is an area of interest and policy has been developed to encourage large-scale RES to include ESS.[17] Stand-alone ESS facilities can function within the grid or 'behind the meter' to address demand and price fluctuations as well as regulation services in systems with high shares of renewable energy.[18]

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[13] P. Denholm; Jorgenson, J.; Hummon, M.; Palchak, D.; Kirby, B.; Ma, O.; O'Malley, M. "Impact of Wind and Solar on the Value of Energy Storage." *NREL Report No. TP-6A20-60568* Golden, CO: National Renewable Energy Laboratory (2013): 10.

[14] Anya Castillo and Dennice F. Gayme. "Grid-scale energy storage applications in renewable energy integration: A survey." *Energy Conversion and Management* 87 (2014): 886.

[15] Marissa Humman, Paul Denholm, Jennie Jorgenson, David Palchak, Brendan Kirby and Ookie Ma. "Fundamental Drivers of the Cost and Price of Operating Reserves." *NREL/TP-6A20-58491* Golden, CO: National Renewable Energy Laboratories (2013):46.

[16] M. Dicorato, G. Forte, M. Pisani, and M. Trovato. "Planning and Operating Combined Wind-Storage System in Electricity Market." *IEEE Transactions on Sustainable Energy* 3 (2) (2012): 216.

[17] Ontario. Ministry of Energy. *Achieving Balance - Ontario's Long Term Energy Plan*. Toronto, Ontario: Queen's Printer for Ontario. (2013): 33.

[18] Ken Elser, Patrick Milligan, and Aditya Chintalapati. *California's Energy Storage Mandate: Challenges, Opportunities, and Implications* (2014): 3, 12.

Summary: Policy Review

This section focuses on electricity policy and regulatory environment including historic regulations, Ontario's 2013 Long Term Energy Plan and barriers to energy storage deployment.

Historic electricity policy reflects the characteristics and limitations of conventional generation technologies and thus is organized around just-in-time generation and consumption.[19][20] The unbundling of electricity systems has been undertaken as a method to decrease costs through competitive markets. This regulatory environment has impacts on the development and deployment of energy storage.

The 2013 Ontario Long Term Energy Plan (LTEP) lays out the ten year forecast for energy use in the province, specifying a procurement target of 50MW for energy storage to offset peak demand and reduce the need for construction and expansion of nuclear facilities.[21] Similarly, a new procurement policy for large-scale RES (500MW or larger) is expected to provide opportunities for projects to include storage technology.[22] This appears, in part, to be an effort to make intermittent resources, especially wind power, more dispatchable and thus add flexibility to the grid.

The Plan states that the government will "initiate work to address regulatory barriers that may limit the ability of stored energy resources to compete in Ontario's electricity market."[23] An example cited is that some storage applications are required to pay certain fees (retail, uplift and Global Adjustment) both at the time of capture and at end use.[24] This research will discuss regulatory changes that may be implemented to address these barriers.

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[19] IESO. "Energy Storage." *Independent Electricity System Operator.* Accessed 23 February 2015.

[20] Bruce Dunn, Haresh Kamath, and Jean-Marie Tarascon. "Electrical Energy Storage for the Grid: A Battery of Choices." *Science* 334 (2011): 929.

[21] Ontario. Ministry of Energy. *Achieving Balance - Ontario's Long Term Energy Plan*. Toronto, Ontario: Queen's Printer for Ontario. (2013):7.

[22] Ibid., 33.

[23] Ibid., 83.

[24] Ibid., 86.

Technology Overview

The general purpose of an energy storage system (ESS) is to consume overproduction of electricity and hold it as either electrical or another form of energy (ie. thermal or kinetic) to be released at times of high consumption or to meet some other system requirement.

There are several electrical system requirements that can be met with energy storage such as arbitrage, voltage regulation, frequency regulation, curtailment reduction, spinning and non-spinning reserves, and demand response.

Energy storage is technologically complex because there are numerous emergent technologies which are able to store energy including pumped-hydroelectric storage (PHS), compressed air energy storage (CAES), lead-acid (LAB) and Lithium-ion batteries (LiB), flywheels, super-capacitors, thermal and chemical devices (including hydrogen), and vanadium redox-flow batteries (VRFB).

Because of the emergent nature of many of these technologies there is no way to ensure effective grid-scale operation without undertaking demonstration projects. PHS is a proven and widely implemented technology which is often used for time-shifting and load levelling. Globally, there appear to be only two active grid-scale CAES facilities in operation. Batteries have been implemented only at small scales; demonstration sites exist in Japan for VRFB, though lead-acid and lithium-ion batteries have not been put through rigorous testing for grid-scale operation. Flywheels have seen use in smaller projects and mobile applications; a combined flywheel/battery system of 12MW has been procured by Ontario’s Independent Electricity System Operator (IESO). Super-capacitors are being considered for residential storage solutions but are considered by some to be inappropriate for grid-scale applications. There is a 0.74MW thermal storage system included in Phase 1 of Ontario’s procurement plan.

Review of Technology

> "Storage technologies are characterized by energy and power capacities, which can be important deployment considerations. For example the limited energy capacity of flywheels and some batteries restricts them to short-duration services such as regulation."[25]

The following section will discuss several energy storage technologies, their technical operation, benefits, and limitations as well as practicability for Ontario.

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[25] Ramteen Sioshansi, Paul Denholm, and Thomas Jenkin. "Market and Policy Barriers to Deployment of Energy Storage." *Economics of Energy and Environmental Policy Journal* 1 (2) (2012): 47.

Pumped Hydro Storage

Pumped hydroelectric storage (PHS) is one of the most widely implemented energy storage technologies worldwide because of its relative simplicity and the ease with which it can be combined with hydroelectric dam projects which already require a reservoir. Estimates of global capacity suggest that there are currently more than 127GW of PHS in operation.[26] Ontario has several PHS facilities in operation in conjunction with river dam projects including Adam Beck Pumping Station at Niagara Falls. A new PHS system was recently procured, built and operated by NRStor Inc., which utilizes a decommissioned open-pit mine in Marmora, Ontario.[27]

Description

Pumped Hydro Storage (PHS) is variously described as Pumped Storage Hydroelectric (PSH) and Hydro Pumped Storage (HPS). The technology relies on low-lying reservoirs in close proximity to elevated reservoirs. Water is pumped to the elevated reservoir when electricity is in low demand and released through turbines to the lower reservoir during times of high demand. Fuchs et al. state that “the amount of stored energy is proportional to the product of the total mass of water and the altitude difference between the reservoirs.”[28] This means that the capacity is almost infinitely variable and that systems are limited only by topography, the availability of land which enables construction of two reservoirs of different elevations, and geography, the proximity of appropriate topography to electrical demand.

Benefits

PHS has been in use since the early 20th century and is considered to be mature, though Fuchs et al. state that technological advancements in turbine and generator design may allow

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[26] Georg Fuchs, Benedikt Lunz, Matthias Leuthold, and D. U. Sauer. "Technology Overview on Electricity Storage." ISEA, Aachen, Juni (2012). Pg.18.

[27] Shawn McCarthy. “In eastern Ontario, a battery five times the size of Niagara Falls.” *The Globe and Mail* 19 February 2013.

[28] Fuchs et al., 18.

slight efficiency improvements.[29] The round-trip efficiency of PHS, which is a measure of the energy required in the process of storing and releasing electricity, is estimated by Fuchs et al. at 75% - 82% which is partially maintained by a low self-discharge rate.[30] This is incredibly efficient compared to most other storage technologies and is coupled with an expected lifespan of 80 years.[31]The speed with which PHS can be dispatched, about 3 minutes, also makes it attractive for various applications including frequency control, voltage control, peak shaving, and standing reserves.[32]

PHS is grouped alongside other traditional generation technologies in the present regulatory frameworks, which disregards the flexibility options it can provide.[33]

Limitations

PHS requires specific geography to function; valleys or large depressions are required to contain the large bodies of water formed by the reservoirs and one reservoir must be elevated compared to the second to ensure appropriate water pressure through turbines. Because PHS requires vast areas to act as reservoirs for stored water resources, Fuchs et al. state that ecological considerations have precluded the use of rivers in many places and that “the biggest challenge is to find suitable spaces for lower reservoirs.”[34] Discussing the European outlook for PHS, the authors suggest that large-scale hydro storage reservoirs which presently operate by storing

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[29] Ibid., 18.
[30] Ibid., 18.
[31] Ibid., 19.
[32] Ibid., 19.
[33] Oghenetejiri Harold Anuta, Phil Taylor, Darren Jones, Tony McEntee, and Neal Wade. "An International Review of the Implications of Regulatory and Electricity Market Structures on the Emergence of Grid Scale Electricity Storage." *Renewable and Sustainable Energy Reviews* 38 (0) (2014): 495.
[34] Sameer Hameer and Johannes L. van Niekerk. "A Review of Large-Scale Electrical Energy Storage." *International Journal of Energy Research* (2015): 1108.

seasonal runoff for later use could be adapted to redirect water back into storage rather than released into the river system, though this has further ecological considerations.[35]

These ecological considerations limit the use of PHS by extending the approval process and requiring environmental impact assessments while some high environmental standards disallow the damming of many rivers.[36]Additionally, because of the scale of development and associated transmission lines, the return on investment can be as long as 30-50 years.[37]

Feasibility for Ontario

Ontario is geographically appropriate for PHS and possesses numerous facilities already. Sir Adam Beck Pump Generating Station is located at Niagara Falls and has a capacity of 174MW.[38] The facility was built in 1957 and diverts water from the main generators at night, when demand is low, into a 300 hectare reservoir where it is kept until demand increases.[39] The Marmora Pumped Storage Hydro facility is a 400MW system procured by the IESO and currently under construction by Northland Power in a decommissioned open pit mine.[40]

Compressed Air Energy Storage

Description

Compressed Air Energy Storage (CAES) similarly relies upon geological formations, in this case underground caverns or reservoirs. At times of low demand, electricity is used to compress air in a cavern or reservoir. When demand is high, the stored air is expanded and mixed with natural gas then burned to increase heat energy and passed through a turbine to

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[35] Fuchs et al., 18.

[36] Ibid., 18.

[37] J. Paska, P. Biczel, and M. Klos. "Technical and Economic Aspects of Electricity Storage Systems Co-Operating with Renewable Energy Sources." *10th International Conference on Electrical Power Quality and Utilisation* (2009): 4.

[38] O'Malley et al., 9.

[39] IESO. *RFP for Energy Storage Services Backgrounder*. Toronto:Independent Electricity System Operator. (2014): 1.

[40] McCarthy.

generate electricity, quickly meeting demand.[41] To store energy, air is compressed by a motor-driven compressor, this process heats up the air and a radiator is required to remove heat as the air is directed into the cavern. During discharge the air is expanded, causing it to cool and often requiring the use of natural gas or bio-fuel for reheating, and used to drive a turbine/generator to produce electricity. [42] There are two types of CAES, defined by the method of dealing with waste heat from the compression process; diabatic is the method in which heat is removed and then fuel is used to reheat the air during discharge, the adiabatic method is emissions-free and stores excess heat for use in the discharge process.[43]

Benefits

CAES is relatively low cost and, unlike PHS, has a small surface footprint because it utilizes underground caverns or reservoirs. Like PHS, the technology is dependent upon the use of specific geography, in this case well-sealed caverns, and has a round-trip efficiency of 55% - 70%.[44] The lifespan of CAES systems, including the turbines, compressors, and heating systems, is approximately 25 years and can be used for frequency control, voltage support, peak shaving, load levelling, standing reserves and black start.[45]

Konrad et al. state that there are two major ways that CAES can benefit an electrical system; "The first is an arbitrage mode where energy is stored to leverage low off-peak energy prices against higher peak prices. The second proposed mode of operation is in conjunction with renewable energy sources like wind farms."[46] The systems can also be used as spinning reserves because of the ability to quickly change the output to meet increased demand and load balancing

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[41] Konrad, James, Rupp Carriveau, Matt Davison, Frank Simpson, and David S-K Ting. 2012. "Geological Compressed Air Energy Storage as an Enabling Technology for Renewable Energy in Ontario, Canada." *International Journal of Environmental Studies* 69 (2): 351.

[42] Fuchs et al., 21.

[43] Ibid., 21.

[44] Ibid., 22.

[45] Ibid., 23.

[46] Konrad et al., 350.

when demand changes, as Konrad et al. state, "by either storing or generating energy as demand requires."[47]

Two grid-scale diabatic CAES facilities are in use globally, a 290MW facility built in 1978 in Huntorf, Germany and another of 110MW built in 1991 in McIntosh, Alabama, USA.[48]

Limitations

CAES facilities face limitations regarding the availability of caverns or reservoirs of sufficient size with appropriate geology within close proximity to electrical demand centres. The caverns must be able to contain high-pressure air and therefore may suffer from high self-discharge rates.

The thermal storage technology required for adiabatic CAES, such as molten salt storage, is still under development and is not yet available commercially which limits the pursuit of this type of system.[49] Because of the use of fuels for heating, the round-trip efficiency of diabatic systems is at the low end of the potential range and thus only large-scale systems with long returns on investment are economically viable.[50] This large size also reduces the ability of CAES to fulfill the role of addressing transmission and distribution issues.[51]

Feasibility for Ontario

Konrad et al. conducted a study to determine the geological feasibility of CAES in Ontario and found that areas of high wind power deployment coincide with appropriate geology. The southern perimeter of the Precambrian Shield in the region of Sarnia and elsewhere, under

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[47] Konrad et al., 352.

[48] P. Denholm; Fernandez, S.J.; Hall, D.G.; Mai, T.; Tegen, S. (2012). "Energy Storage Technologies," Chapter 12. *Renewable Electricity Futures Study*, *Vol. 2*, Golden, CO: National Renewable Energy Laboratory. (2012):12-10.

[49] Fuchs et al., 21.

[50] Ibid., 23.

[51] Ibid., 23.

Lake Erie, were found to be ideal for containing pressurized gases.[52] Additionally the authors state that the carbonate reefs of the Guelph Formation, under which reservoirs are presently used for natural gas storage, and salt bearing strata of the Salina Formation have potential for CAES.[53] The facilities at Huntorf, Germany and MacIntosh, Alabama both utilize solution-mined caverns in salt. This process is employed in southwestern Ontario and the authors suggest that this indicates particular promise for CAES prospects. [54]

Two recent CAES projects are proposed or under development in Ontario. First, a 1000MW facility designed for long-term storage is in development by NRStor, General Compression and SustainX and was announced on March 31, 2015.[55] Second, HydroStor has developed an underwater adiabatic CAES system which is proposed to be located in Lake Ontario and works by inflating air bags to store energy and releasing this air to run turbines and generate electricity. The proposed system has a capacity range of 1MW-30MW with a discharge range from 3-20 hours.[56]

Battery Storage

Batteries all operate in a similar way; electrical energy is converted into chemical energy during charging and then discharged as electrical energy. Batteries are made up of cells containing positive and negative electrodes, cathode and anode respectively, between which charged ions move when charging and discharging. The electrodes do not touch one another directly; ions are suspended in electrolyte which can be made of various substances.

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[52] Konrad et al., 355.

[53] Ibid., 356.

[54] Ibid., 355.

[55] "NRStor brings new energy storage technology to Ontario, reducing emission and saving billions for rate-payers." *Canadian News Wire* 31 March 2015.

[56] Jean Kumagai. "Hydrostor Wants to Stash Energy in Underwater Bags." *IEEE Spectrum* 14 July 2014.

The most popular battery types for large-scale storage include Lead-Acid, Lithium-ion, high-temperature Sodium-Nickel-Chloride and Sodium-Sulphur, and flow batteries such as Vanadium Redox-Flow. Lead-acid and Lithium-ion batteries are similar in that they operate at low temperatures and utilize a liquid electrolyte. High temperature batteries use a solid electrolyte which must be heated to a liquid state for operation. Flow batteries, of which Vanadium Redox-Flow is the most popular, utilize a liquid electrolyte which is pumped through a central reaction chamber.

Lithium-ion Batteries

Description

Lithium-ion batteries (LiBs) use an electrolyte of lithium salts dissolved in organic carbonates and are made with a positive electrode of lithiated metal oxide and a negative electrode of layered graphitic carbon.[57] During the charging process lithium ions move from positive to negative are intercalated, or inserted, into the graphite layers and during discharge the ions move into the crystal structure of the lithiated metal oxide.[58]

The most common use for LiBs is for short- and medium-term storage in portable applications but according to Fuchs et al. "several demonstration projects with lithium-ion battery containers exist in the Europe, while in the US lithium-ion battery storage containers are already used in weak grid areas"[59]

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[57] Hameer and van Niekerk, 1111.
[58] Fuchs et al., 41.
[59] Ibid., 41.

Benefits

With round trip efficiencies of 83%-86%[60] and incredibly fast deployment time of 3-5 milliseconds,[61] LiBs are ideal for frequency and voltage control, peak shaving, and load levelling. The size and safe operational characteristics make LiBs useful for mobile applications and residential storage systems.[62] These batteries have been the subject of intense improvement and innovation because of their use in the automotive industry and have very high energy density, high performance and a lifespan that varies based on depth of charge between 5 – 20 years.[63]

Limitations

The nature of LiBs can lead to thermal runaway, requiring each cell to be monitored and thus sophisticated management systems have been developed to control temperature and charging profiles, increasing costs. Fuchs et al. state that LiBs may suffer from social acceptance problems due to lithium mining in problematic countries and because lithium resources limited to only a few countries this could have an impact on availability.[64]

Lead-Acid Batteries

Description

Lead-acid batteries (LABs) use an electrolyte of sulfuric acid dissolved in water and are made with electrodes of lead. During the charging process ions move from the electrolyte into the lead plates and during discharge they move from the electrodes into the electrolyte solution. This type of battery makes up the largest installed capacity and is among the oldest, well-

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[60] Ibid., 42.
[61] Ibid., 42.
[62] Ibid., 42.
[63] Ibid., 42.
[64] Ibid., 42.

developed and widely used energy storage technologies. Fuchs et al. describe a successful grid-scale LAB storage plant in Berlin with a power rating of 17MW and operational capacity of 14MWh which was used for frequency control beginning in 1986.[65]

Benefits

Lead-acid batteries are relatively low-cost and thus short return on investment because of wide commercial availability and have round-trip efficiency of 75%-80% and a lifespan of 5-15 years.[66] Their quick deployment time, 3-5 milliseconds, enables them to fulfill several system requirements such as frequency control, peak shaving, and load levelling as well as serving micro-grids, residential storage systems and as uninterruptable power supply.[67] Because of the large number of uses and manufacturers, there are already a high number of existing LABs with acceptable energy and power density for stationary applications and, unlike LiBs, require no complex cell management.[68]

Limitations

The greatest limitation to the use of lead-acid batteries is environmental hazard; the two major components are toxic and the cells are very temperature sensitive.[69] Because of their long history and widespread use, recycling programs are in place and have a high rate of capture and reuse, reducing the amount of toxic lead released into the environment.[70] Technical complications arise because of the asymmetrical charging and discharging abilities, ventilation

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[65] Ibid., 43.
[66] Ibid., 43.
[67] Ibid., 44.
[68] Ibid., 45.
[69] Paska et al., 3.
[70] Fuchs et al., 43.

requirements, and limited lifecycle.[71] Lead-acid batteries are also vulnerable to future legislation aimed at reduction the use of heavy metals and to competition from Lithium-ion batteries.[72]

High-Temperature Batteries

Description

The two types of high-temperature battery commercially available are Sodium-Nickel-Chloride ($NaNiCl_2$) and Sodium-Sulphur (NaS). Both have a solid state electrolyte, instead of fluid, which must be operated at 270-350°C to get sufficiently high ion conductivity and transfer the active masses into fluid condition.[73] When the battery is cooled down, charging or discharging is not possible and there is the danger of cracks in the ceramic electrolyte. Fuchs et al. suggest that these batteries are useful for applications with daily cycling, but are inappropriate for long-term storage.[74]

Benefits

High-temperature batteries can be built with high capacities and have round trip efficiency of 75-80% and a lifespan of 15-20 years. [75] Like other battery systems they have a quick deployment time, 3-5 milliseconds, which is appropriate for system requirements such as frequency control, peak shaving, and load levelling as well as serving micro-grids, residential storage systems and as uninterruptable power supply. They can utilize relatively inexpensive raw materials and have no special site requirements, making them incredibly versatile.[76]

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[71] Ibid., 45.
[72] Ibid., 45.
[73] Ibid., 46.
[74] Ibid., 46.
[75] Ibid., 47.
[76] Hameer and van Niekerk, 1112.

Limitations

Fuchs et al. suggest that high thermal standby losses and the potential hazard posed by the high operating temperature, which contributes to a high incidence of fires, may limit their deployment to some degree.[77]

Flow Batteries

Description

Flow batteries possess an active material made up of salt, which is dissolved in a fluid electrolyte. The electrolyte is stored in tanks. During charging and discharging the electrolyte is pumped through a central reaction chamber where current is applied. The capacity and power are variable based on tank size and reaction unit (cell stack) of the battery.[78] The most common type is the Vanadium Redox-Flow Battery and several demonstration projects exist, mainly in Japan where facilities of 100kW or more are used for load-levelling purposes. [79] The applications are variable from medium (1-10 hours) to long-term (several weeks) because of the customizable nature of the technology.[80]

Benefits

The main advantage described by Fuchs et al. is "independent scaling of power and energy," which enables facilities to be adapted for numerous applications including storage at a weekly time scale.[81] With round trip efficiency of 60%-70%, depending on the chemistry they

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[77] Fuchs et al., 47.
[78] Ibid., 38.
[79] Ibid., 38.
[80] Ibid., 38.
[81] Ibid., 38.

may be more efficient when used for medium and long-term storage.[82] The calendar life of flow batteries is estimated at 10-15 years and the deployment time is measured in seconds. [83]

Limitations

Flow batteries rely upon acidic fluids and as such concerns include leakage, pump and valve failure, and cell life, all of which increase the cost of maintenance and repair.[84] The acid content also presents a legal problem for site selection. Fuchs et al. state that current vanadium systems are too expensive for storage periods of a few days and hourly storage with flow batteries has no advantage over lead-acid or high-temperature batteries.[85]

Feasibility for Ontario

Battery storage systems have few limitations in regard to site selection and several projects are under construction or in operation in Ontario.

RES Canada has constructed an energy storage system called Amphora which consists of a 4MW flywheel and a 2.6MW Lithium-ion battery which is intended to provide frequency regulation to the southwestern Ontario utility Entegrus.[86]

Canadian Solar Solutions has been awarded a contract to build and operate a 4MW Lithium-ion battery system to provide reactive power, voltage support and bulk energy services to the IESO.[87]

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[82] Ibid., 39.

[83] Ibid., 39.

[84] Ibid., 40.

[85] Ibid., 40.

[86] "RES Canada Announces Completion of Energy Storage System." *Canadian News Wire* 5 August 2014.

[87] Robin Whitlock. "Canadian Solar to Supply 4MW Energy Storage Solution to Support the Ontario Grid." *Renewable Energy Magazine* 14 November 2014.

Super-Capacitors

Description

Super-capacitors operate by storing energy in the electrical field between two electrodes of opposite polarity which are separated by an electrolyte.[88] During charging electrical opposing charges of equal magnitude are held on the surface of each electrode and during discharge the circuit is completed, releasing the charge and creating a current.[89] Compared to batteries they have a very high cycle life and power density but a much lower energy density which makes them useful for short-term storage.[90]

Benefits

The round trip efficiency of super-capacitors can be as high as 90%-94%[91] and they have a lifespan of 15-20 years.[92] An incredibly fast deployment time of less than 10 milliseconds combined with high power capability makes them useful for frequency and voltage control as well as peak shaving.[93] As compared with most batteries, super-capacitors are not temperature sensitive and there is no danger of overcharging.[94]

Limitations

The biggest limitation of super-capacitors is low energy density; the average electrochemical battery holds five to ten times the energy with considerably less self-discharge.[95]

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[88] Roger Peters and Lynda O'Malley. *Storing Renewable Power.* Drayton Valley, Alberta:The Pembina Institute (2008): 29.

[89] Peters and O'Malley, 29.

[90] Fuchs et al., 26.

[91] Ibid., 27.

[92] Peters and O'Malley, 30.

[93] Fuchs et al., 27.

[94] Peters and O'Malley, 30.

[95] Ibid., 31.

Super-capacitors also have very high costs per installed energy and are often utilized in conjunction with batteries which limits the impact of this cost.[96]

Feasibility for Ontario

No super-capacitor storage projects have been deployed in Ontario. Canadian company Sunvault Energy has developed a graphene-based super-capacitor which they intend to introduce to the residential energy storage market.[97]

Flywheel Storage

Description

Flywheel systems store kinetic energy during the charging process by accelerating a rotating mass such as a disc which remains spinning until energy is required. Advanced mechanics are used, vacuums and magnetic bearings for example, to minimize rotational resistance. During discharge, kinetic energy is extracted by a generator which is driven by the inertia of the flywheel.[98] A common application for flywheels is for short-term storage to smooth output such as grid stabilization for trains and subways where they perform regenerative braking by absorbing kinetic energy during braking and deliver power during acceleration. [99] With round trip efficiency of 80-90% and calendar life of 15 years, flywheels are relatively low cost solution for short-term storage. [100] Fuchs et al. state, “Flywheels perform well for applications which

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[96] Fuchs et al., 27.

[97] “Sunvault Energy Enters into Agreement with Edison Power Company to Retail Power in Alberta.” *MarketWatch* 14 April 2015.

[98] Peters and O’Malley, 27

[99] Fuchs et al., 24.

[100] Ibid., 25.

demand very high power for only short time with a high number of charging-discharging cycles and only short storing periods."[101]

Benefits

Flywheel are able to charge and discharge very quickly, 10 milliseconds or less, and have very low maintenance requirements compared to chemical storage systems.[102] The characteristics of the technology make it ideal for frequency and voltage control, peak shaving and mobile applications.[103]

Limitations

Individual flywheels are not ideal for large capacity grid-scale applications because of low energy density.[104] Physical damage of the system can occur due to the dynamic load which exerts pressure on the container and bearings.[105] Due to their high self-discharge rate flywheels are not ideal for longer storage times.[106]

Feasibility for Ontario

As stated above RES Canada has constructed an energy storage system called Amphora which consists of a 4MW flywheel and a 2.6MW Lithium-ion battery which is intended to provide frequency regulation to the southwestern Ontario utility Entegrus.[107]

NRStor has constructed a 2MW flywheel energy storage facility which will be operated under the company name Temporal Power and deliver regulation service.[108]

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[101] Ibid., 24.
[102] Ibid., 25.
[103] Ibid., 25.
[104] Peters and O'Malley, 29.
[105] Fuchs et al., 25.
[106] Ibid., 25.
[107] "RES Canada Announces Completion of Energy Storage System." *Canadian News Wire* 5 August 2014.
[108] "Minister of Energy and NRStor Announce First Grid-Connected Energy Storage Facility in Ontario." *Canadian News Wire* 22 July 2014.

Hydrogen Storage

Description

Hydrogen storage stores energy by utilizing off-peak electricity to produce hydrogen through an electrolyzer which separates water into hydrogen and oxygen. The hydrogen is compressed and stored in a reservoir from where it is discharged into a fuel cell or burned to drive a turbine.[109] The round trip efficiency of this process is very low, 30-50%[110], but fuel cells can hold energy in high densities and at high capacities over long time periods.[111] Fuchs et al. suggest that for the outlook for hydrogen storage is positive because it works well for large scale and long term energy storage (weekly, monthly, seasonal), and in this application the low cost for capacity will outweigh the inefficiency of conversion.[112]

Benefits

Hydrogen storage has been touted as a technology that will enable emissions-free transportation but for grid-scale applications it also has several benefits. Coupled with underground reservoirs or caverns very large amounts of energy can be stored and the media component is water, which is available in large quantities.[113] The deployment time is approximately 10 minutes, making it ideal for medium to long-term storage including seasonal arbitrage.[114]

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[109] Fuchs et al., 33.
[110] Peters and O'Malley, 32.
[111] Ibid., 32.
[112] Fuchs et al., 33.
[113] Ibid., 35.
[114] Ibid., 34.

Limitations

The major limitation of hydrogen storage is the high cost for electrolyzers. [115] Other issues include low efficiency, which limits its ability to serve short-term applications and technical complications in matching the high voltage electricity generated by renewable energy generators and the lower voltage required for electrolysis.[116]

Feasibility for Ontario

Hydrogenics has been selected to build and operate a 2MW hydrogen-based power-to-gas project in conjunction with Enbridge.[117] The facility will use excess production from renewable energy systems to electrolyze hydrogen from water which will then be injected into Enbridge's natural gas pipeline network.[118]

Thermal Storage

Description

Thermal energy storage (TES) charges by converting electrical energy into thermal energy and discharges by converting thermal energy back into electrical energy. There are several methods to achieve this and different media are used in each. High temperature thermoelectric energy storage (TEES) systems use electricity or a heat pump to heat a medium such as magnesium oxide or molten salt to around 500°C.[119] During discharge the heat is extracted to produce steam and drive a turbine which generates electricity.[120] Another method of high temperature thermal energy storage is to use concentrated solar power (CSP) to heat a

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[115] Fuchs et al., 35.

[116] Peters and O'Malley, 33.

[117] "Hydrogenics and Enbridge to develop utility-scale energy storage." *The Associated Press* 23 April 2012.

[118] "Hydrogenics Selected for 2 Megawatt Energy Storage Facility in Ontario." *Market Watch* 25 July 2014.

[119] Fuchs et al., 30.

[120] Ibid., 30.

storage medium which reduces conversion losses because the energy is only converted to electricity for discharging.[121] Low temperature, end-use thermal storage such as a hot water tank charged with an electric heater can be controlled with computer-based management systems to convert energy back to electricity and aggregated to provide demand response.[122]

Benefits

Thermal energy storage systems are useful for short and medium-term application such as frequency and voltage control, peak shaving, load levelling and standing reserves.[123] Denholm and Mehos suggest that high temperature thermal energy storage can be combined with concentrating solar power (CSP) so that the thermal medium is heated using solar energy.[124] The high round trip efficiency of TES, estimated at 95%, makes it attractive as a tool to increase the flexibility and dispatchability of solar energy and provide firm system capacity.[125]

Limitations

According to Fuchs et al. thermal storage technology is in the early stages of development and there are few grid-scale demonstration projects.[126] Strasser and Selvam provide a detailed list of sixteen operational CSP/TES ranging in size from 5-250MW as well as a further twelve which are under construction.[127] Strasser and Selvam state that the major limitation of TES is high cost for storage tanks, storage medium and heat exchangers.[128]

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[121] Matthew N. Strasser And R. Paneer Selvam. “A cost and performance comparison of packed bed and structured thermocline energy storage systems.” *Solar Energy* 108 (2014): 391.

[122] Fuchs et al., 7.

[123] Ibid., 31.

[124] Denholm Paul and Mark Mehos. “Boosting CSP Production with Thermal Energy Storage.” *PowerMag.com* (2012). Accessed 02 April 2015.

[125] Denholm and Mehos.

[126] Fuchs et al., 31.

[127] Strasser and Selvam, 392.

[128] Ibid., 393.

Feasibility for Ontario

Dimplex North America and VCharge have been awarded a contract to build and operate a 750kW thermal energy storage system in a social housing complex to provide frequency regulation and grid stability. The system replaces standard electric baseboard heaters with storage heaters designed by Dimplex that consume electricity at off-peak times to heat up ceramic bricks which release warmth to the residence and which can convert the thermal energy back into electricity. Once the individual units are installed and connected through network management software, the aggregated units act as a single 750kW thermal storage system capable of providing frequency regulation and energy to the grid.[129]

Conclusions

The diversity of storage technologies and their numerous applications present opportunities for Ontario to address a variety of issues within the electricity system including firming the stochastic production profiles of intermittent renewables, relieving congestion in transmission and distribution networks and deferring system upgrades, and providing frequency and voltage regulation and other ancillary services.[130] All of these benefits enable to grid to accept higher penetrations of renewable energy and decrease Ontario's reliance on nuclear and fossil fuel-based generation.

For energy storage to be successfully integrated into the Ontario electrical system regulators, investors, developers and utility operators must have clear understanding of the characteristics of storage technologies. This will aid in addressing policy and regulatory issues which present barriers to deployment.

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[129] St. John, Jeff. "VCharge is Turning 'Hot Bricks' Into Grid Batteries." *Greentech Media* 02 April 2014.
[130] IESO. "Energy Storage." *Independent Electricity System Operator.* Accessed 23 February 2015.

Renewable Energy Penetration

Introduction

Energy storage has particular benefits for electricity systems with a high share of renewable energy generation. As Ramteen et al. state, “Another area of interest is storage’s role in enabling greater penetration of variable renewable sources.”[131] Renewable energy systems (RES) have characteristics and impacts upon electrical networks that may be smoothed or alleviated with the use of energy storage systems (ESS).

Renewable resources are often considered to be intermittent because of natural fluctuations. Wind and solar irradiance for example change with local and regional weather conditions and therefore the productivity of generators which utilize these resources fluctuates as well. The term variable generation is also used to describe the relative unpredictability of intermittent renewables. Energy storage has been proposed as a solution to the intermittency of renewables.

Another outcome of the stochastic generation patterns of renewable technologies is a lack of dispatchability. In electrical grids dispatch is the term which describes meeting consumption demands. With conventional generation output is controllable and relatively constant so that increases or decreases in demand can be balanced by ramping output up or down. The daily patterns of generation from intermittent resources will not necessarily match the patterns of demand and the generators output electricity only when the resource is productive. Energy storage can be used to increase the dispatchability of renewable energy.

Curtailment of renewable energy is a tactic utilized to address intermittency by reducing output at times of low demand. Often output is curtailed from renewable facilities to balance

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[131] Sioshansi et al., 53.

system loads with generation but can result in reduced revenue for these plants which influences future investment in renewables. Energy storage can be employed to minimize the impact of curtailment on renewable penetration by charging with the energy production that would otherwise be curtailed.

Another reason for curtailment is transmission bottlenecks such as under capacity transmission lines. For a variety of reasons transmission and distribution (T&D) network operators are forced to curtail renewable energy which impacts both revenue and development potential for RES. Energy storage can be used to address transmission bottlenecks and maximize the amount of renewable energy that is delivered to consumers.

Grid regulation services are required for the smooth operation of electrical systems and are typically provided by conventional generation plants in lieu of power capacity. Renewables are usually not required to provide grid services and, partly of intermittency, increase the need for certain services within the grid. A solution to this problem is to make RESs provide grid services in the same way that conventional facilities must, through contract requirements. Alternatively, energy storage is capable of providing grid regulation services separate from power generation.

Long term storage concerns arise in electrical systems with a high share of renewables because in addition to daily changes in output there are monthly and seasonal fluctuations which may result in periods of reduced production. To achieve an energy system entirely composed of renewable energy requires assurance that demand can be met at all times regardless of resource availability. Energy storage that is capable of meeting days to weeks of demand would enable a much higher penetration of renewables.

Co-location of ESS and RES is proposed as an elegant solution to the high investment cost of both renewable technology and storage technology. Combining the two facilities into a larger system provides a generation plant that is able to function effectively as a conventional generator. Co-location has been shown to improve the economics of both technologies and increase potential penetration.

Policy linking ESS and RES is intended to ensure that energy storage facilities are charged using electricity produced only from renewables. The foundational concept is that this type of policy would help increase penetration of renewables while supporting innovation and development of storage technology. Many policies supporting the integration of renewables have been implemented throughout the world with great success but these do not necessarily support energy storage.

Intermittent Resources

Many scholars suggest that energy storage will benefit renewables because of their intermittent nature. Renewable energy systems based on intermittent resources, such as wind and solar irradiance, generate electricity only when those resources are productive. Anuta et al. suggest that without proper planning and management there are many negative effects to the electrical system from high penetration of renewable energy because of unpredictable generation patterns including technical and economic impacts on generation, transmission and distribution (T&D) networks and electricity markets.[132] Del Granado et al. state that intermittency of wind is a serious challenge to the electrical grid because generation and demand do not coincide.[133] The ability to store large amounts of energy can make this intermittent generation more dispatchable

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[132] Anuta, et al., 491.

[133] Pedro Crespo Del Granado, Stein Wallace, and Zhan Pang. "The Value of Electricity Storage in Domestic Homes: A Smart Grid Perspective." *Energy Systems* 5 (2) (2014): 212.

and able to match consumption patterns. The primary technical challenge of integrating renewables, Denholm and Hand state, is the variability of the resource at scales from seconds to months and suggest that energy storage systems (ESS) can provide the technical capability to alleviate this variability.[134] Anuta et al. also recommend that energy storage should be considered as a tool to alleviate the impact of intermittency and meet targets for the adoption of renewable energy systems.[135]

Dispatchability

The term dispatchability describes the process of meeting electricity demand with a particular generator at the moment that it is required. Intermittent renewable energy generators are considered to be non-dispatchable because generation, and thus the ability to deliver energy to meet consumption, is dependent upon the productivity of the resource. Advocates assert that for renewable sources to deliver a larger proportion of energy capacity it must be 'firmed' through the use of storage technology. In this way ESS will act as an enabling technology for renewable energy. Konrad et al, discussing the practical application for compressed air energy storage (CAES), state that the technology has the potential to "supplant the variability and lack of dispatchability in wind generation." [136] Similarly, Harris et al. state that energy storage can improve the use of renewable energy by converting intermittent resources into dispatchable

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[134] Paul Denholm and Maureen Hand. "Grid Flexibility and Storage Required to Achieve very High Penetration of Variable Renewable Electricity." *Energy Policy* 39 (3) (2011): 1817.

[135] Anuta et al., 504.

[136] James Konrad, Rupp Carriveau, Matt Davison, Frank Simpson, and David S-K Ting. 2012. "Geological Compressed Air Energy Storage as an Enabling Technology for Renewable Energy in Ontario, Canada." *International Journal of Environmental Studies* 69 (2): 358.

resources which “increases the utilization of inexpensive, efficient baseload generators, and reduces the use of single-cycle gas turbines and older, more inefficient generators.”[137]

Curtailment

Intermittent resources will often produce more electricity than is needed by the system to meet simultaneous demand. When this happens output from these plants must be reduced, or curtailed, to balance the system. Denholm and Hand describe curtailment as a form of dispatchability in that by curtailing output, variable generators are able to match reductions in demand and balance the electrical grid.[138] Energy storage can help minimize the impact of curtailment by redirecting the electricity generated when the resource is productive into a storage medium so it can be dispatched when demand is higher. This is especially important for wind turbines for two reasons. First, unlike turbines powered with water or steam, wind speed is variable and so the speed of the turbine and its power output is also variable.[139] Second, wind production tends to peak in the morning while demand peaks in the afternoon.[140] At higher penetrations, Denholm and Hand state, intermittent renewables will experience reduced output more often because once the threshold for curtailment is reached all additional generation will be curtailed.[141] The lack of correlation between variable generation and demand can be mitigated by energy storage which is able to shift generation to meet demand. Denholm and Hand’s models suggest that a small amount of storage can be used to shift hourly peaks but that the economics

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[137] Chioke Harris, Jeremy P. Meyers, and Michael E. Webber. "A Unit Commitment Study of the Application of Energy Storage Toward the Integration of Renewable Generation." *Journal of Renewable and Sustainable Energy* 4(1) (2012): 12.

[138] Denholm and Hand, 1818.

[139] N. Miller and P. E. Marken. "Facts on Grid Friendly Wind Plants.” *IEEE2010 Power and Energy Society General Meeting* (2010): 1.

[140] Denholm, and Hand, 1823.

[141] Ibid., 1823.

are less clear for the greater amounts of storage needed to meet longer time frames.[142] Their models found that 4 hours of storage decreased curtailment in wind farms by 43% while 8-12 hours of storage only decreased curtailment 7.7% and that reducing the rate of curtailment below 10% would require storage capacity of approximately one day of average demand.[143]

Transmission Bottlenecks

The intermittent nature of renewable resources also contributes to higher cost per delivered watt of electricity because the infrastructure is only used when the resources are delivering electricity to the grid. To make the infrastructure investments for intermittent renewable energy systems (RES) more economically feasible transmission lines are often sized to deliver less capacity than the system is capable of delivering at peak production. This increases curtailment because the transmission capacity is less than the generation capacity. The electricity cannot be dispatched to meet demand and therefore generator output must be reduced. Energy storage can be used to make transmission investments for large renewable energy systems more economic by storing energy onsite when transmission capacity is constrained for dispatch when the transmission network has available capacity.

In many jurisdictions with unbundled electricity markets storage facilities are classified as generators and, as a result of regulation designed to ensure competitive markets, T&D network operators are prevented from owning and operating generators. In Europe, Anuta et al. found that unbundling of the electricity market came with regulations, based on EU Directive 2009/72/EC, that preclude T&D operators from controlling electricity generation as a way of discouraging anti-competitive behaviour.[144] Additionally, T&D network operators may incur

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[142] Denholm and Hand, 1825.
[143] Ibid., 1825.
[144] Anuta et al., 496.

significant expense when renewable output is curtailed as a result of transmission constraints due to policies favouring renewables. Anuta et al. state that because priority is given to renewable generators under EU Directive 2009/72/EC T&D operators must compensate RES owners for curtailing output to address transmission bottlenecks. The authors relate that events of huge compensation paid by transmission system operators (TSOs) to RES owners to curtail excess energy have been recorded in the UK and Germany.[145] This is beneficial for RES owners but detrimental to overall system efficiency and presents a limitation to the volume of real power delivered from renewables. Without the ability to directly own and operate ESS, T&D network operators cannot take advantage of the potential benefits of these technologies for their networks to address problems of variable generation and the intermittency of renewables.

Regulatory frameworks of this type drastically reduce the deployment prospects for ESS as a tool to address the transmission and distribution impacts of increased penetration of renewable energy. Economic benefits pertaining to utility cost deferral are complex and it isdifficult to estimate avoided costs.[146] If T&D network operators are able to invest in ESS to relieve transmission constraints, Anuta et al. state, the money currently spent on curtailing excess energy from RES can be invested in ESS solutions for RES capacity firming, deferring or reducing the need to carry out expensive network upgrades or reinforcements.[147]

Grid Regulation Services

Renewables are described by many academics as requiring more grid regulation services than thermal generation. Among the most important applications of storage in a system with high shares of renewables, as stated by Fuchs et al., are "...primary frequency control and voltage

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[145] Anuta et al., 496.
[146] Elser et al., 10.
[147] Anuta et al., 505.

control as these services were traditionally supplied by conventional power plants."[148] Other grid regulation services, such as fast response ramping, are needed with intermittent renewable because they generate electricity in a stochastic manner as compared to the steady, controllable output of thermal generation. Grid services are required for smooth operation of the electricity system regardless of generation technology but are typically provided by centralized generators in lieu of capacity as part of bilateral agreements.

For renewable energy to make up a larger proportion of electrical generation a different method of delivering grid services is required. ESS facilities are capable of providing grid services separately from generation capacity which may enable increased development of RES plants. In their discussion of grid connected wind farms, Miller and Marken identify a major limiting factor as the imposition of grid codes that demand regulation services, which are required under many bilateral agreements with conventional power plants, from wind farms.[149] The authors describe the critical role of power electronics in improving grid integration for wind farms that dispatch energy directly to the grid. While power electronics are one solution, these technologies add cost to the system while performing a role that could be served by ESS, which also has the capability to provide other services to the grid.

If not properly planned and managed, RES integration can also lead to negative secondary effects, both technical and economic, that can affect the utilization and performance of generation, T&D networks, and the electricity markets.[150] Anuta et al. identify bi-directional power flow at high voltage levels, unpredictable generation patterns and high daily peak demand, power system stability and power quality issues, voltage excursions and system stability as

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[148] Fuchs et al., 50.

[149] Miller and Marken, 1.

[150] Anuta et al., 491.

potential problems that could arise.[151] The inclusion of ESS into electrical systems may allow unique solutions to the provision of grid services such as the use of telecom backup systems for spinning reserves and harmonic filtering proposed by Akel et al. to participate in Ontario's contractual demand reduction program, DR3.[152]

Long Term Storage

In addition to daily fluctuations, intermittent resources are variable at longer time scales; generated capacity can change week to week and seasonally. Energy storage may be able to limit the impact this may have on an electrical system as renewables begin to make up a larger proportion of generation capacity. In Greece, strict limitations are placed on the amount of electricity wind farms are allowed to release to the grid to ensure grid stability and maintain minimum operation of base load generators.[153] The daily and seasonal fluctuations of resource availability and load demand do not always coincide and so wind generation often must be curtailed. Kaldellis et al. suggest that pumped hydro storage (PHS) could be used to store the wind energy and reduce reliance on fossil fuel-based generators.[154] The authors describe the barriers to penetration faced by wind energy production in Greece because of daily and seasonal fluctuations and technological limitations in place to and suggest that if long term fluctuations can be alleviated by utilizing storage then system limitations for penetration of renewables would be eased, increasing market penetration and investment value of wind generation.[155]

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[151] Anuta et al., 491.

[152] Nabil Akel, Tom Bowker; Victor Goncalves. "Dual-Purposing Telecom Backup Systems for Cloud Energy Storage and Grid Ancillary Services." *IEEE 36th International Telecommunications Energy Conference* (2014): 4.

[153] J.K. Kaldellis, M. Kapsali, K.A. Kavadias. "Energy balance analysis of wind-based pumped hydro storage systems in remote island electrical networks." *Applied Energy* 87 (2010): 2427.

[154] Kaldellis et al., 2430.

[155] Ibid., 2430.

Large-scale long term storage such as PHS is not feasible in many places but as new technologies are developed and renewables make up a larger proportion of the electrical system it may become more important. For example, Fuchs et al. found that roughly once in a decade Europe experiences "so called 'dark calm' periods"[156] during which there is almost no wind throughout the continent. These periods do not pose a problem in a system with a broad portfolio of generator technologies but if the primary mode of generation is renewable resources then long term storage capacity would be a pragmatic solution. The authors state that storage may be the only solution for this type of event because interconnection and transmission capacity, while helping to distribute renewable across larger areas, does not help when production is reduced so greatly."[157]

Co-location of RES and ESS

The coupling of renewable energy with energy storage has generated interest as a way to take advantage of the aforementioned mutual benefits to increase the economics of both systems and increase overall system resilience. Del Granado et al. state that ESS coupled with wind turbines has a higher investment value than either system alone, "which implies that wind power and ESS are economic complements."[158] Alan Lamont, in his assessment of the economic value of electricity storage found that large investments in any individual intermittent renewable generator will tend to drive down prices because of a glut of simultaneous generation, which can discourage investment.[159] Introducing energy storage provides a system load during these periods as the storage systems charge, increasing prices and the economic viability of renewable

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[156] Fuchs et al., 51.
[157] Ibid., 51.
[158] Crespo Del Granado et al., 230.
[159] Lamont, 920.

investments.[160] By locating both systems on the same site, overall efficiency and economic viability are improved while integration of renewable becomes easier as well. To alleviate the fact that many renewable energy systems cannot provide firm power, Leighty and Holbrook suggest a storage system designed as a buffer between the intermittent generator and the grid, reducing significantly the impact on the electrical system.[161] In their study the authors propose an electrolyzer-based storage system that is charged with on-site renewable and interacts with the grid only as a generator, providing clean electricity produced 'behind the meter'.[162] Similarly, Konrad et al. recommend wind farms co-locate a CAES facility to be charged at off-peak times and released to the grid when required, which they state serves to "increase wind power penetration into the North American electricity market by making it 'dispatchable'."[163] Richardson and Harvey conducted a study comparing array orientation, geographic dispersal and the use of storage to increase the correlation of solar PV output and electricity demand in Ontario and found that PV combined with energy storage is the best method to increase correlation. The authors suggest that the combination of PV and storage is more beneficial to the system and may assist in the integration of solar PV into the electrical system.[164]

Co-location can be seen as a solution to intermittency and for this purpose, Anuta et al. state, the expectation is that ESS be located close to the RES, improving dispatchability, but this may not be the optimal position on the grid to relieve congestion problems.[165] Despite this, the

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[160] Lamont, 912.

[161] Leighty, William C. and John H. Holbrook. "Alternatives to Electricity for Transmission, Firming Storage, and Supply Integration for Diverse, Stranded, Renewable Energy Resources: Gaseous Hydrogen and Anhydrous Ammonia Fuels Via Underground Pipelines." *Energy Procedia* 29 (2012): 334.

[162] Leighty et al., 334.

[163] Konrad et al., 351.

[164] Richardson, David B. and L. D. D. Harvey. "Strategies for Correlating Solar PV Array Production with Electricity Demand." *Renewable Energy* 76 (2015): 440.

[165] Anuta et al., 501.

authors suggest that co-location results in improved access to the grid and reduced network connection charges. [166]

Policy Linking ESS and Renewables

Storage systems can be charged with electricity from any source and many advocates propose regulations and incentives that encourage the use of ESS to support RES investments. Sioshansi et al. positively review several programs in the United States including a federal investment tax credit (ITC) of 30% for new storage investments and California Assembly Bill 2514 which according to the authors is similar to a Renewable Portfolio Standard (RPS).[167] The purpose of an RPS is to mandate a proportion of the electricity that must be procured from sustainable sources thus encouraging investment in renewable generation technologies. Anuta et al. recommend plans, targets and goals for the use of ESS similar to those implemented for renewables such as ITCs and RPSs.[168] This type of subsidy may make ESS more attractive to private investors proposing large-scale RES in unbundled electrical systems.

Carson and Novan recommend that any incentives for ESS include certification of renewable origin as a way of ensuring the storage systems are charged only with energy from renewables. [169] The authors argue that a potential outcome of grid-scale bulk storage is an increase in unregulated emissions because fossil fuel-based generators will likely be used to charge storage systems.[170] This creates further conflict in the creation and adoption of regulations

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[166] Anuta et al., 504.

[167] Sioshansi et al., 57.

[168] Anuta et al., 505.

[169] Richard T. Carson and Kevin Novan. "The Private and Social Economics of Bulk Electricity Storage." *Journal of Environmental Economics and Management* 66 (3) (2013): 423.

[170] Carson and Novan, 423.

and incentives for storage as, without certification of renewable origin, there is no assurance that ESS policies will encourage investment in renewable energy. [171]

Conclusions

Intermittent renewables in Ontario face dispatchability and curtailment issues that can be addressed with the implementation of energy storage systems for time shifting. Similarly, variable generation based on intermittent resources increases the need for grid regulation services to increase and maintain power quality. The province can benefit from the utilization of medium term storage to minimize the impact of bottlenecks in transmission and distribution networks exacerbated by changing generation and demand patterns. As the portion of renewables continues to rise in Ontario weekly and seasonal fluctuations in generated capacity can be smoothed through the use of long term storage. The co-location of storage facilities with renewable energy systems increases generator stability and may unlock the potential for greatly increased penetration of renewable energy in Ontario.

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[171] Krajačić, Goran et al. “Feed-in Tariffs for Promotion of Energy Storage Technologies.” *Energy Policy* 39 (3) (2011): 1412.

Policy Review

Introduction

Energy storage can be utilized for various applications within an electrical system but several historical policy frameworks act as barriers to deployment. According to my research there are three overarching policy issues in unbundled markets, like Ontario's, which limit the development and utilization of ESS to serve these system needs. First, historic policy considers electricity to be a resource which cannot be stored and existing regulatory frameworks are intended to encourage efficient operation of a just-in-time electricity system. Second, technological uncertainty; the multiple uses of energy storage make it hard for regulators to understand potential applications, the lifespan of many technologies is uncertain, and the nascent stage of development is reflected in high costs. Third, market uncertainty; organization and separation of markets prevents network and utility operators from owning certain types of facilities, classification guidelines increase proposal and initiation costs for developers, and the lack of markets for services that storage can provide makes it less attractive to private investors.

As the IESO is undertaking an exploratory phase of energy storage development[172], regulators can increase the potential for energy storage deployment by addressing the common issues of regulatory barriers and preference for other solutions, technological cost and uncertainty, and market risk and uncertainty.

Regulatory Barriers

Historic policy considers electricity to be a resource which cannot be stored and existing regulatory frameworks are intended to encourage efficient operation of a just-in-time electricity system. A regulatory preference for other technology and solutions such as fossil fuel-based

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[172] IESO. "Energy Storage." *Independent Electricity System Operator.* Accessed 23 February 2015.

generators and demand response limits the consideration of energy storage is borne through the ways that the system is organized based on the operational capacities and limitations of conventional technology.

Just in Time Generation

Until recently, grid-scale electricity storage has been accomplished almost exclusively through the use of a single technology; pumped hydroelectric storage (PHS). The majority of electrical systems operate on the basis that electricity cannot be stored and therefore must be generated and consumed simultaneously.[173] Government policy and market regulation regarding electrical systems has been guided by this principle.[174] As new technologies are developed, tested and made available for grid-scale applications the models used for policy and regulation may need to change to accommodate the potential for energy storage to support the system.

Valuation of Services

Existing policies contractually obligate generators to provide other grid services in lieu of generating capacity; the value of these services is determined by the opportunity cost of lost generation, thereby devaluing the services that can be provided by ESS. As Quereshi et al. state in regard to the regulated market, “valuation of storage usually only considered the ability of storage to provide two basic classes of services – firm capacity and ‘load leveling’.”[175]

Sioshansi et al. state that “One of the more commonly cited barriers to the deployment of storage is the inability to quantify and capture the multiple value streams provided to the grid.”[176] Without access to multiple markets, energy storage is less able to generate revenue and becomes

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[173] Waqar A. Qureshi, Nirmal-Kumar C. Nair, and Mohammad M. Farid. “Impact of Energy Storage in Buildings on Electricity Demand Side Management.” *Energy Conversion and Management* 52 (2011): 2111.

[174] Zhao Xu Donghan Feng and Jacob Østergaard. "Redesign Electricity Market for the Next Generation Power System of Renewable Energy and Distributed Storage Technologies." *IEEE PES General Meeting* (2010): 1.

[175] Sioshansi et al., 50.

[176] Sioshansi et al., 50.

less attractive to private investors. By allowing storage to operate in several markets regulators enable developers and operators to increase revenue, thereby making the technology more attractive to investors.

Unbundled Markets

In recent decades many countries have adopted an unbundled or market-based approach to grid management. Under this model the government creates regulations governing the operation of the electrical grid but encourages private investors to build, own, and operate generation facilities as owner operators. In these markets the main objective of a facility from the owner's perspective is to generate profit by providing services to the utility, transmission, or distribution operator. As ESS technologies begin to be integrated into electrical grids, they too are encouraged to generate revenue by providing services to the system, often by exploiting price volatility through arbitrage; storing inexpensive energy during off-peak times and releasing it during on-peak times. [177] This revenue method is most effective in a system characterized by low penetration of ESS technology because the introduction of large amounts of storage capacity is shown to reduce price volatility, thus reducing potential profits from arbitrage.[178] In a system which recognizes the value of ESS, the operators of storage facilities would be rewarded for the services provided to the system rather than only by exploiting price volatility.

Asset Classification

Asset classification ensures that individual facilities can only be used for supporting transmission, distribution or generation. An ESS that is classed as a transmission asset may not

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[177] Hadi Khani and Mohammad R. Dadash Zadeh. "Online Adaptive Real-Time Optimal Dispatch of Privately Owned Energy Storage Systems using Public-Domain Electricity Market Prices." *IEEE Transactions on Power Systems* 30 (2) (2014): 2.

[178] A. M. Abeygunawardana, K. Anula and Gerard Ledwich. "Estimating Benefits of Energy Storage for Aggregate Storage Applications in Electricity Distribution Networks in Queensland." *IEEE Power & Energy Society General Meeting* (2013): 2.

be able to provide firm capacity, demand response (DR) or ancillary services (AS). The current framework “may have been sufficient for the centralized thermal generation and transmission line power system...” but “...clear lines of differentiation in this framework may result in unnecessary inefficiency.”[179] Additionally, the prevention of regulated monopolies from participating in the electricity market prevents transmission and distribution (T&D) network operators from owning ESS that can influence the electricity market.[180] Castillo and Gayme state that in many systems, because of historic regulation, energy storage is assigned to provide only a single service in a single market and precluded from being compensated from the numerous services it is capable of offering.[181] In the UK, Anute et al. state that undetermined asset classification of ESS affects its viability because rules applicable to both generation and demand functions are applied individually to ESS.[182]

To maintain institutional and market segregation individual electrical system facilities are usually classified as generation, transmission or distribution assets.[183] This classification determines which set of regulations and policies the asset operates under, how it is able to be utilized and how costs can be recovered.[184] Assets are often disallowed from operating in more than one market to ensure market integrity, a principle that has important impacts on energy storage. Sioshansi et al. describe two regulatory decisions regarding cost recovery that illustrate this point. The first ESS was part of a transmission upgrade and proposed to be operated by the ISO to maximize transmission relief with cost recovered from the rate base; this was rejected by regulators who concluded that the facility would be providing generation services and therefore

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[179] Duruv Bhatnagar, Aileen Currier, Jacquelynne Hernandez, Okkie Ma, and Brendan Kirby. *Market and Policy Barriers to Energy Storage Deployment*. A Study for the Energy Systems Program. Albuquerque, New Mexico: Sandia National Laboratories (2013): 22.

[180] Anuta et al., 492.

[181] Castillo and Gayme, 891.

[182] Anuta et al., 492.

[183] Sioshansi et al., 54.

[184] Ibid., 54.

the ISO could interfere in other markets.[185] The second ESS was proposed for transmission relief as well but developers explicitly stated that the facility would only provide transmission services, ensuring market independence; this facility was granted rate base cost recovery.[186] The result is that energy storage facilities will be built based not on the needs of the system, nor the best application of technology, but upon the regulations and accounting standards which determine how costs are recovered.

The creation of a new asset class for energy storage would allow ESS to operate across other classes and provide grid services wherever they are needed. This approach has been explored in Texas where ERCOT has exempted certain pilot projects from regulations to gain experience with storage facilities and inform future energy storage rules.[187] Alternatively, removing asset classification restrictions for energy storage would allow use of emerging technologies without further complicating the regulatory environment.

Bhatnagar et al. state that at the federal level in the United States, FERC has determined that all uses of energy storage can be accommodated by existing asset classifications and a new classification will yield no additional benefits.[188] Additionally, the authors suggest that a new classification may increase system and regulatory complexity and act as a barrier to deployment.[189]

Transparency

Lack of transparency in pricing, including grid tariffs and fees, increases the modelling and proposal costs while reducing their effectiveness, acting as a deterrent to investment. Anuta

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[185] Sioshansi et al., 55.
[186] Ibid., 55.
[187] Bhatnagar et al., 46.
[188] Ibid., 24.
[189] Bhatnagar, et al., 24.

et al. find that the unbundling of electricity systems leads to a lack of transparency in generation, supply and network activities. This affects the assessment of ESS across the electricity system.[190]

Lack of transparency in regulatory proceedings may inhibit development of ESS as well. Bhatnagar et al. state that "Administrative delay in the implementation of new regulations to address barriers to energy storage deployment itself presents a barrier to deployment."[191] Similarly the authors relate that developers "...may wait until rules are in place and vetted before considering and deploying storage resources."[192]

Anuta et al. suggest that the difficulty in assessing value in the electricity markets is due to the vertically integrated behaviour of supply and generation utilities affecting electricity market liquidity, and changing market conditions affected by external world events (such as natural disasters), changing policies, economics and operational factors.[193]

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[190] Anuta et al., 492.
[191] Bhatnagar et al., 21.
[192] Ibid., 21.
[193] Anuta et al., 492.

Technological Cost and Uncertainty

The multiple uses of energy storage make it hard for regulators to understand potential applications, the lifespan of many technologies is uncertain, and the nascent stage of development is reflected in high costs. As stated previously, there are generally two ways that electricity markets are organized; regulated and unbundled (also called competitive). In an unbundled market there may be a utility which has monopolistic control over some aspects of the system but under which competitive markets exist for private investors to build and operate facilities to provide services to the utility. For ESS to be viable in a regulated market the utility operator need only prove that the technology can serve a system requirement. For ESS to be economically viable in an unbundled market the technology must serve a system requirement and generate revenue for private investors through markets, which is presently not possible for many storage technologies.

Multiple Applications

A major complication regarding energy storage policy is that there are several applications for ESS and organization of electricity markets has generally led to separation of each function of the system into distinct classifications and markets. Generation, transmission, and distribution are each governed by different sets of regulations which attempt to maximize efficiency and direct the market towards least-cost delivery of electricity to consumers. Because energy storage has multiple functions and can serve several markets, regulatory frameworks which integrate all potential functions are complex.

Energy storage has multiple applications for electrical grids but is often precluded from use by regulatory rules that have been designed for traditional assets which serve only one function.[194] Bhatnagar et al. identify these regulatory restrictions as an issue faced by other technologies as well, including conventional generators, but state that it is especially limiting for energy storage because it is most beneficial when providing services across classifications.[195]

Castillo and Gayme suggest that a way around this limitation is the use of storage by vertically integrated utilities because they can maximize the grid benefits of storage and rate-base the investment but this may not be possible in unbundled markets.[196]

High Technology Costs

The use of energy storage is impeded by high costs for technology, construction and operation. While costs vary, many ESS technologies are relatively new and therefore have high costs associated with commercial products which are not yet manufactured at large scales. The construction of ESS facilities requires significant capital investment and may justify the use of alternatives to storage at the present time such as curtailment and transmission upgrades.[197] Bhatnagar et al. interviewed regulators, utilities and developers and found that technology costs have led some, such as Colorado's Public Service Company and the Midcontinent ISO, to use alternatives to energy storage for economic reasons.[198] Elser et al., discuss challenges to meeting the California energy storage mandate and state that for a storage technology to have a net benefit the costs should range from USD$1000-4000/kW, based on a study done by the Electric Power Research Institute.[199] This includes construction and operation of the facility and varies depending upon the specific technology.[200]

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[194] Castillo and Gayme, 891.

[195] Bhatnagar et al., 22.

[196] Castillo and Gayme., 891.

[197] Bhatnagar et al., 34.

[198] Ibid., 34.

[199] Elser, Ken, Patrick Milligan, and Aditya Chintalapati. *California's Energy Storage Mandate: Challenges, Opportunities, and Implications* (2014): 3,10.

[200] Elser et al., 3,10.

In the case of end user storage, Kantor et al. found that the high cost of residential storage systems presents a barrier to implementation.[201] This is beginning to change, Tesla Energy's Powerwall, which utilizes battery systems battery technology designed for the company's electric cars, is available in sizes of 7kWh for $3,000 and 10kWh for $3,500.[202]

Incentives, subsidies and other government programs can help reduce the cost of technology in some cases and encourage innovation in energy storage. One solution, described by Sioshansi et al., is an investment tax credit (ITC) such as a federal program in the USA which provides a 30% ITC for new storage investments. [203] Another approach is California Assembly Bill 2514 which mandates a program for energy storage deployment of 1,325MW[204]. This mandate is intended to be similar to a Renewable Portfolio Standard (RPS) and encourages investment by requiring utilities to integrate storage assets into the grid.[205] Kantor et al. suggest that a subsidy program for residential storage would be reasonable in Ontario based on historical incentive programs to manage demand as well as the FIT program.[206]

Cost Recovery

The high technology costs for ESS can be mitigated somewhat by taking advantage of multiple uses and combining benefits to recover costs through several avenues.[207] The segregation of markets means that storage facilities can only be given a license to operate in a single market. For ESS to provide congestion relief to a transmission service operator (TSO), for example, it must receive approval to operate in that market, precluding it from providing grid

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[201] Kantor et al., 222.

[202] Sophia Stuart."Tesla Energy Launches with 'Powerwall' Home Batteries." *PC Magazine PCmag.com.* 01 May 2015.

[203] Sioshansi et al., 57.

[204] Elser et al., 3.

[205] Sioshansi et al., 57.

[206] Kantor et al., 225.

[207] Abeygunawardana et al., 1.

support services such as voltage support, which is organized under a separate market.[208] This type of market design constraint was intended to ensure efficient operation of each market in a paradigm of non-storable electrical energy but acts as a barrier to the implementation of energy storage.[209]

Anuta et al. argue that to ensure maximum investor returns in an unbundled electricity market, and reduce uncertainty regarding cost recovery, storage should be considered for its multiple functions and be allowed to determine competitively which services are best served by storage technologies.[210] For example, under the present market paradigm ESS is paid for actual energy discharged to the grid like conventional generation technologies but it could be rewarded for the total energy consumed and injected by a “mileage payment.”[211]

Technological Uncertainty

Energy storage technologies are not understood well by regulators for a variety of reasons including a lack of experience and the rapid pace of development. If electricity system stakeholders do not understand the capabilities and applications for ESS they will not consider storage when making investment decisions.[212]

The lack of demonstration projects for many technologies contributes to a lack of knowledge regarding the construction costs, operational characteristics, lifespan, and potential revenue. Evans et al. suggest that even for PHS, one of the most widely used storage technologies, uncertainty about future water availability affects further implementation.[213]

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[208] Castillo and Gayme, 888.
[209] Sioshansi et al., 51.
[210] Anuta et al., 500.
[211] Ibid., 500.
[212] Bhatnagar et al., 32.
[213] Lewis Evans and Graeme Guthrie. "How Options Provided by Storage Affect Electricity Prices." *Southern Economic Journal* 75 (3) (2009): 694.

Because new storage systems are being developed at a rapid pace it is hard for regulators and investors to ascertain the best application for a technology. This may lead them to prefer proven technologies to address issues within the grid. Hydrogen storage, for example, has only been utilized in demonstration projects so investment costs have to be estimated based on system components which increases resistance to implementation.[214]

Operational Cost

In addition to investment costs, technological uncertainty is present with regard to operational costs as well. For a business case to be made for any storage facility, investors must have knowledge of the type and frequency of discharges in order to estimate operation and maintenance costs and place a value the facility's services.[215] These costs are hard to predict for some technologies partly because of the lack of demonstration projects but more importantly because of the complex impacts that storage has on grid operation. Sioshansi et al. state that another concern when attempting to estimate operational costs is the ability for storage "to reduce generator ramping and cycling..." which can become "...increasingly important as variable renewable place added strains on conventional generators."[216]Additionally, grid tariffs and fees applied during both charging and discharging add to operational costs.[217] In their study of ESS limitations in the UK, Taylor et al. note that while storage may meet the technical requirements for balancing and system regulation, storage is too expensive in part because of high grid charges for transmission and distribution (T&D).[218] The authors suggest that regulators

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[214] M. Kloess and K. Zach. "Bulk Electricity Storage Technologies for Load-Leveling Operation – an Economic Assessment for the Austrian and German Power Market." *International Journal of Electrical Power and Energy Systems* 59 (2014): 114.

[215] Elser et al., 10.

[216] Sioshansi et al., 51.

[217] Anuta et al., 496.

[218] Ibid., 496.

could remove T&D charges as a way of valuing the contribution of storage to improving network operations.[219]

Numerous studies attempt to quantify the operational costs of storage technology and their impact on the electricity system including Harris et al.[220], Evans et al.[221], and Awad et al.[222] Modelling is used to estimate operational costs and revenues but these often cannot capture the full system impacts such as reduced stress on existing generators, which regulators should consider when making strategic decisions.[223]

Anuta et al. state that the only way to reduce uncertainty in regard to these costs is through experience from live deployments which will enable the establishment of standardized methods of evaluation, connection, operation and maintenance.[224]

Market Uncertainty and Risk

Market uncertainty influences the deployment of energy storage in unbundled markets because private investors must prove a business case by showing how costs will be recovered and revenue generated. The organization and separation of markets prevents network and utility operators from owning certain types of facilities which reduces their ability to generate sufficient revenues to justify the high investment cost of storage assets. Market separation also increases proposal and initiation costs for developers because they must prove feasibility for each market in which they propose to operate. The lack of markets for some services that storage can provide, which is a result of historic contracts, makes it less attractive to private investors.

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[219] Anuta et al., 496.

[220] Harris et al.

[221] Evans and Guthrie.

[222] Awad, Ahmed S. A., J. David Fuller, Tarek H. M. El-Fouly, and Magdy M. A. Salama. "Impact of Energy Storage Systems on Electricity Market Equilibrium." *IEEE Transactions on Sustainable Energy* 5 (3) (2014): 875-885.

[223] Sioshansi et al., 4.

[224] Anuta et al., 504.

Market Access

To make the business case for high cost technologies in an unbundled market system access to all potentially profitable markets is required.[225] Castillo and Gayme state that “different revenue streams can potentially increase the value of storage technologies that have a range of technical capabilities...” but “...storage installations are often relegated to performing one particular service (e.g. congestion relief) and eligible to participate in only one market.”[226] In the United States, FERC has recognized the need for multiple market access in Notice of Proposed Rulemaking on Storage Accounting and Financial Requirements.[227] In part this recognizes the thinness of markets for some services, which makes it more difficult for storage assets to recover costs through any single market and.[228] For energy storage to be viable in Ontario it requires access to all available markets.[229]

Ownership Regulations

Partly because of the need to ensure competitive markets, network and utility operators are often prevented from owning and operating certain types of facilities so their ability to utilize storage assets is reduced. Anuta et al. state that transmission (TSOs) and distribution system operators (DSOs) are most likely to require the services provided by storage but they are impeded by regulators from implementing ESS on the grid. [230] Because of the ownership and contracting structures, private investors’ interests may not align with those of the utility operator,

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[225] O'Malley et al., 8.
[226] Castillo and Gayme, 888.
[227] Bhatnagar et al., 22.
[228] Sioshansi et al., 10.
[229] O’Malley et al., 8.
[230] Anuta et al., 496.

increasing the complexity of proving a business case. Elser et al. suggest that these commercial arrangements represent a barrier to energy storage deployment.[231]

Proposal and Initiation Costs

The separation of markets has another unintended consequence for energy storage in that to enter each market a developer must prove a business case within that market. Lack of transparency regarding ESS also leads to increased costs; Bhatnagar et al. relate that in the US, FERC has stated its intention to consider proposals to recover costs through both markets and rate-base methods on a case-by-case basis.[232] The authors suggest that this may act as a barrier because of the cost involved in presenting a case to the commission.[233]

Securing financing for ESS can also be a challenge because of lack of technological experience and cost.[234] Elser et al. suggest that subsidies or tax incentives could defray this risk in the same way that renewable energy subsidies have driven down technology costs and encouraged financiers to invest.[235]

Khani et al. describe the barriers presented by forecast inefficiencies in day-ahead pricing and pre-dispatch prices and their models show that in Ontario as much as 50% of ideal revenue is lost to price inaccuracies.[236] The authors develop a model based on back-casting, in which 24-hour behind market prices are used to optimize ESS, and suggest that this may mitigate some of the inaccuracy and increase revenue.[237] This shows the complexity of modelling required to prove the business case for storage in a market system.

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[231] Elser et al., 3.
[232] Bhatnagar et al., 22.
[233] Ibid., 22.
[234] Elser et al., 10.
[235] Ibid., 11.
[236] Khani et al., 5.
[237] Ibid., 7.

Investment and Development Cost

The cost of deployment is difficult for investors and developers to ascertain in part because of lack of transparency in pricing and rules which make it difficult to determine the long term ROI.[238] As Khani et al. showed, and Lamont et al. further describe, optimal operation presumes perfect foresight over future prices.[239] Though various models attempt to address this for different technologies and applications, such as Hossain et al. who propose a control algorithm for a residential battery storage system[240], there is great difficulty in justifying investment costs through market recovery.[241]

Other issues include risks associated with first-of-a-kind technology such as construction and operational uncertainty, discussed above, and doubts about the state of the market once assets are deployed.[242] The lack of standardized regulations for the use of grid level storage also increases the cost and time necessary for power system stakeholders and third party ESS to build a suitable and sustainable business model for the use of ESS.[243]

Lack of Markets

The unbundling of electricity systems into competitive markets has further impacts on energy storage because of the lack of markets for some services. This is a result of contracts that require the provision of some services alongside generated capacity and which value these

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[238] Sioshansi et al., 6.

[239] Lamont, Alan D. "Assessing the Economic Value and Optimal Structure of Large-Scale Electricity Storage." *IEEE Transactions on Power Systems* 28 (2) (2013): 921.

[240] Md Shakhawat Hossain and M. Tariq Iqbal. "Grid Connected Energy Storage System to Profit from Net-Metering and Variable Rate Electricity." *IEEE 27th Canadian Conference on Electrical and Computer Engineering (CCECE)* (2014): 1.

[241] Sioshansi et al., 9.

[242] Ibid., 10.

[243] Anuta et al., 505.

services based on the opportunity cost of generation.[244] In many places, “grid-services that storage can provide are completely uncompensated” [245]

A solution is to create markets for all services required by the electricity system including ancillary services, black start, voltage regulation and spinning reserve.[246] To address the issues of opportunity cost-based remuneration FERC issued an Order requiring a two-part payment, one for capacity and another for performance, when compensating for frequency regulation.[247]

Policy Conclusions

There are a variety of policy and regulatory barriers to the deployment of energy storage which must be overcome not only to benefit storage technology but overall network efficiency and economy. Many of these issues are the result of historic generation paradigms and the nature of generator technologies. Other issues arise because of the developmental stage of many storage technologies which decreases the ability of regulators, investors and utilities to understand the benefits and applications. The organization of competitive electricity markets and the regulations governing these markets also act as barriers to the deployment of energy storage.

By studying the policy decisions and reviewing the successes of other jurisdictions in integrating energy storage, Ontario can maximize the system benefits of this diverse suite of technologies.

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[244] Marissa Humman, Paul Denholm, Jennie Jorgenson, David Palchak, Brendan Kirby and Ookie Ma. “Fundamental Drivers of the Cost and Price of Operating Reserves.” *NREL/TP-6A20-58491* National Renewable Energy Laboratories (2013): 23.

[245] Castillo and Gayme, 888.

[246] O'Malley, Lynda. *Storage Working Group Briefing Paper*. Toronto, Ontario: Ontario Sustainable Energy Association. (2010): 10.

[247] Bhatnagar et al., 37.

Future Prospects for ESS in Ontario

As the generation mix in Ontario becomes more varied and distributed, through the integration of small-scale generators like solar photovoltaic systems and wind farms, the IESO must integrate many different sources of energy into the existing grid network while meeting demand, which is also becoming varied and distributed. The old electricity paradigm of large centralized generation plants delivering power to concentrated demand centres is being replaced by diffuse networks of producers and consumers, some of which operate as both simultaneously.

Ontario's Long Term Energy Plan (LTEP) states that demand response (DR), through the use of time-of-use (TOU) pricing and conservation programs, is the preferred method in Ontario for meeting this new energy paradigm.[248] While DR is a cost effective manner to address overall system costs it exposes consumers to price volatility which can be mitigated with the use of energy storage systems. For energy storage can be economically viable in Ontario's unbundled electricity market the IESO should update and adapt policy to enable developers to take advantage of its numerous capabilities and applications. For Ontario to achieve a highly efficient, emissions-free electricity system requires the use of energy storage to firm intermittent renewables and provide regulation services. In this way energy storage can facilitate greater penetration of renewable energy generation in the province.

The IESO is already pursuing relatively small-scale integration of energy storage totalling 50MW with the aim of understanding the characteristics of new technologies and gain operational experience. This is a positive course of action and will increase Ontario's knowledge base and provide regulators the opportunity to test policy and market frameworks.

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[248] Ontario. Ministry of Energy. *Achieving Balance - Ontario's Long Term Energy Plan*. Toronto, Ontario: Queen's Printer for Ontario. (2013): 20.

As technological experience increases in the province, proposals are likely to increase which combine renewable energy systems and energy storage facilities to create generators with dispatchability profiles closer to controllable thermal generators.

The province needs to review the policy and regulatory environment and address market barriers to energy storage either through the creation of a new asset class or by enabling storage facilities access to all markets in which its services can be beneficial. Investment and initiation costs need to be reduced to attract investors and the development process must be simplified and standardized for the electricity system, its stakeholders, and consumers to benefit from the multiple applications of energy storage.

Energy storage has a positive outlook in Ontario both for grid management and as a tool to increase the penetration of renewable energy and lead the province to a carbon free electricity future.

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